Chapter 12
Periodic Deflection and Settlement Measurement Surveys (PICES)

12-1. General

This chapter presents guidance for performing field measurements used to determine horizontal deflections and vertical settlements/displacements in structures monitored under the USACE PICES program. This material is intended to supplement and complement EM 1110-2-4300 and should be used in conjunction with the guidance in that reference. Portions of this guidance is in the form of contract specifications, as are used for contracting some aspects of PICES surveys. Standards and specifications for performing precise vertical settlement measurements, crack/joint measurements, and micrometer alignment surveys are covered. These standards are taken from specifications developed by the Jacksonville District in the early 1980s. They were used for both in-house and contracted PICES surveys, and were attached to contract scopes of work. They are generally representative of most USACE deformation monitoring requirements; however, they may not be applicable for PICES surveys on all USACE structures.

12-2. PICES Settlement Monitoring Surveys - General

This section covers standards and specifications for performing precise differential leveling surveys, as required to monitor settlements in concrete and embankment structures. The standards described are developed around precision leveling instruments used for long-distance geodetic leveling runs -- typically compensator (self-leveling) instruments with parallel plate micrometers and dual-scale invar rods with supporting struts. For many structures where level runs are relatively short, this high precision equipment and procedures represents “overkill”-- adequate results may be obtained with more traditional leveling methods (e.g., three-wire or even single-wire observations). Recent improvements in electronic total stations and development of bar code leveling methods are expected to radically change precise vertical survey techniques.

12-3. Vertical Settlement Measurements Using Precise Leveling Techniques

a. Vertical settlement is determined by precision differential leveling methods performed using compensatory auto-collimation leveling instruments with fixed or attached parallel plate micrometers, observing invar double (offset) scale metric rods with supporting struts. In general, one to three fixed reference points (bedrock benchmarks) are used to check for potential movement of various points on the structure. One of the reference points (situated well away from the structure) is held fixed with all subsequent PICES vertical changes tabulated relative to this fixed reference point. Normally an arbitrary elevation is assumed (i.e., 100.000 m); thus the entire structure is on an arbitrary reference datum. Vertical ties between reference bedrock benchmarks are performed only to monitor potential movement on the reference points -- and to enable selection of the best reference point to hold fixed when two or more deep bedrock benchmarks (DBMs) are available. PICES settlement surveys are made infrequently, normally at 6- to 18-month intervals, or sometimes not at all unless there is a suspicion of structural distress.

b. PICES leveling shall be performed in conformance with the methods and accuracy specifications contained in NOAA Manual NOS NGS 3, Geodetic Leveling. Minor variations therefrom are contained within these specifications. Those performing PICES survey work are expected to be thoroughly familiar with the contents of this reference manual. Other applicable references include: ER 1110-2-1806, EM 1110-2-1911, EM 1110-2-2300, and EM 1110-1-1904. This last reference provides guidelines for calculations of vertical displacements and settlement of soil under shallow foundations supporting various types of structures and under embankments.

12-4. Required/Expected Accuracy of Vertical Measurements Using Differential Leveling

Settlement measurement accuracies, relative to the presumed rigid deep bedrock benchmarks, should be on the order of +/-0.002 m, depending upon the leveling distances involved, stability of the reference benchmark, short-term vertical movement in the structure, and other factors. The differential leveling procedures employed should yield 0.001 m (short term) accuracies for most typical structures. High precision geodetic leveling procedures have been modified to meet specific PICES accuracy requirements.

12-5. Definitions

The following definitions apply to differential leveling monuments, instruments, and procedures:

Structure Settlement Point: any point on a structure to which differential leveling is run. May be a disc (Benchmark or BM), survey marker disc, grouted bronze plug with insertable caps, etc.

DBM: Deep (bedrock) Benchmark.

RDBM: Reference Deep (bedrock) Benchmark. This is the same as a DBM except that this mark is that held fixed for relative movement analysis.

Double Run/Double Rod (DR/DR) Leveling: for new PICES projects or for re-observing misclosures from single run/double rod leveling.

Single Run/Double Rod (SR/DR) Leveling: for recurring PICES projects, i.e., one-way leveling. Primary leveling procedure employed for most projects.

Spur Leveling: one-way single rod leveling used for tying in points in a close proximity. Spurred from main DBM or RDBM Single Run/Double Rod level line.

Internal Misclosure: results from Double Run/Double Rod leveling (forward/backward runs).

External Misclosure: comparing single run or spur leveling results with data obtained on previous PICES observations.

12-6. PICES Project Requirements and Instructions for Settlement Observations

Project instructions for continuing PICES projects will generally list (in tabular form on previous PICES reports) those structural settlement points requiring updated elevations (or differential changes from previous readings), and the specific RDBM to be held fixed. Specific leveling routes will be at the discretion of the field party chief, as is the need for single run or double run leveling. Construction requirements for either new deep bedrock benchmarks or new structural settlement monitoring points will be detailed if required.

12-7. Instrumentation and Equipment Requirements

The instrumentation used should meet the requirements for First-Order geodetic leveling -- employing either spirit levels or compensator levels with micrometers, or bar code levels.

a. Recording formats. Any acceptable version of the NGS Micrometer Leveling form may be used -- an 8.5-inch by 11-inch loose-leaf format. Field books and data recorders are also acceptable. Level sketches and abstracts shall also be prepared on 8.5- by 11-inch size loose-leaf paper. A sample recording form is shown in Figure 12-1.

b. Observing procedures. Precise differential leveling methods shall conform to the general methods outlined in Chapter 3 of NOAA Manual NOS NGS 3, as modified herein for either double rod, single rod, or spur leveling. All level lines between RDBMs, DBMs, and structure monitoring BMs shall be run using SR/DR precise leveling methods. DR/DR leveling methods are required only on new PICES projects or when single run lines do not meet external misclosure tolerances.

c. Single or Double Run/Double Rod leveling procedures.

(1) Sections shall not exceed 1 km in length.

(2) Each section shall start and end with the head rod (Rod A) on the BM or reference point. This prevents an accumulation of rod index errors due to an uneven number of setups.

(3) The head rod (Rod A) is always observed first on each setup, whether backsight or foresight.

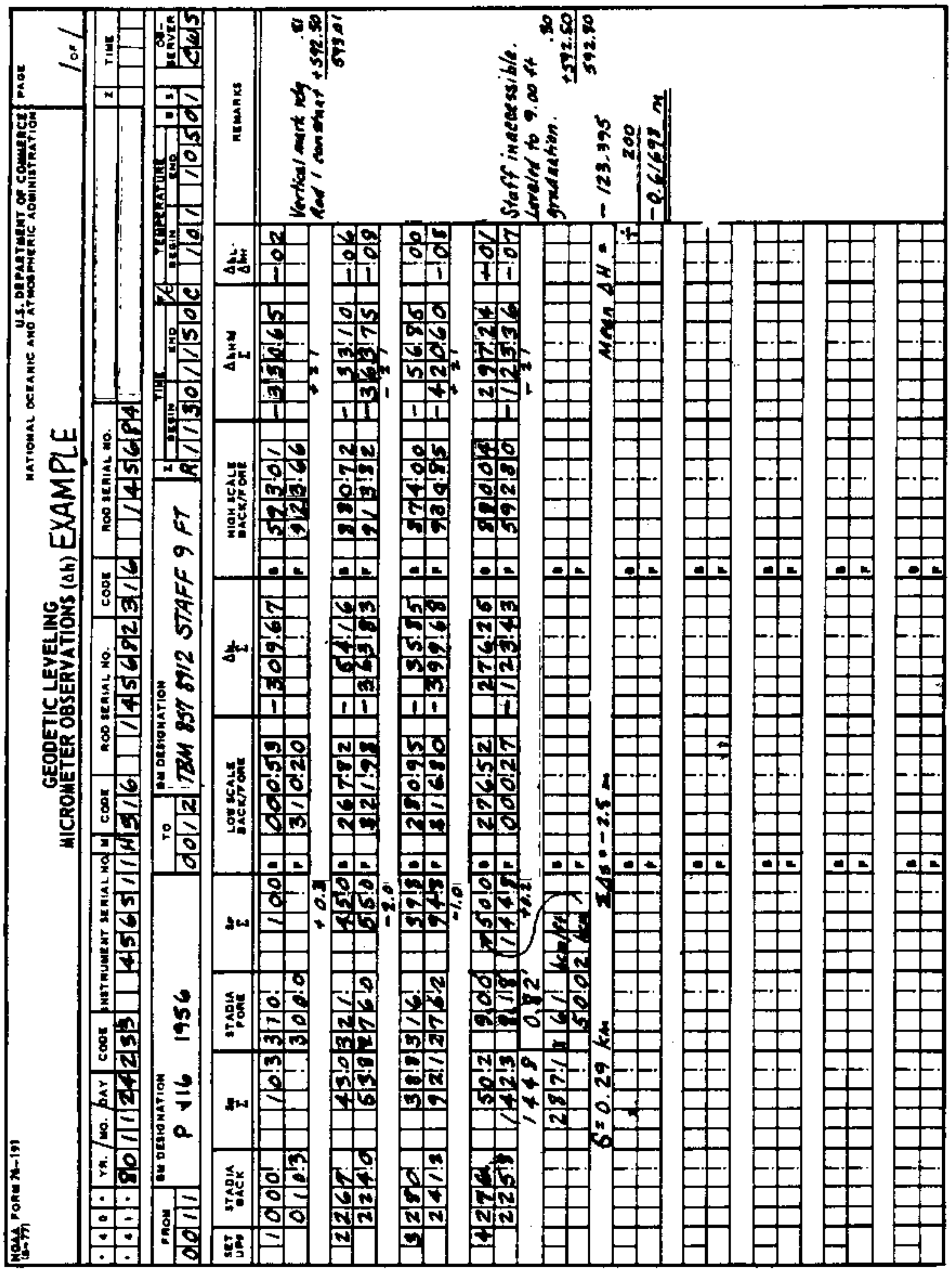
(4) The instrument is leveled with the telescope pointing toward the head rod (Rod A) -- thus alternating toward the backsight and foresight at alternate instrument stations.

(5) The line of sight between instrument and rod should always be higher than 0.5 m above the ground surface. Maximum line of sight distance shall not be greater than 40 m.

(6) Any given setup will be re-observed if the disagreement between the left and right side scale elevations on either rod exceeds 0.25 mm for that setup.

(7) Backward and forward stadia distances can differ by no more than 2 m per setup and 4 m accumulated along a section. (Note: 1-m tolerance for spur leveling.)

(8) Turning plates should not be used on turf; driven turning pins will be required in this type of terrain.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GEODETIC LEVELING
MICROMETER OBSERVATIONS (Δh) EXAMPLE

YR.	MO.	DAY	CODE	INSTRUMENT SERIAL NO.	M	CODE	ROD SERIAL NO.	CODE	ROD SERIAL NO.
80	11	24	25	456511	H	316	145692	316	145694

FROM	BM DESIGNATION	TO	BM DESIGNATION	Z	TIME BEGIN	TIME END	F/C	TEMPERATURE BEGIN	TEMPERATURE END	OBSERVER
0011	P 416 1956	0012	TBM 857 8912 STAFF 9 FT	R	1130	1150	C	101	1050	CWS

SET UPS	STADIA BACK	Σ	STADIA FORE	Σ		LOW SCALE BACK/FORE	Δh Σ		HIGH SCALE BACK/FORE	ΔhH Σ	ΔhL−ΔhH
1	000	10.3	310	100	B	00059	−30967	B	59301	−35065	−02
	013		300		F	31020		F	92366		
				+0.3						+21	
2	267	45.0	321	45.0	B	26782	−6416	B	38072	−3310	−06
	2240	53.8	2760	55.0	F	32198	−36383	F	91332	−36375	−09
				−2.0						−27	
3	280	38.8	316	97.8	B	28095	−3585	B	57400	−5686	00
	2413	92.1	2762	94.8	F	31680	−39968	F	93985	−42060	−08
				−1.0						+21	
4	276	50.2	900	75.0	B	27652	27626	B	58008	29724	+01
	2253	142.3	818	144.8	F	00027	−12343	F	59280	−12336	−07
		1448	0.82'	+2.2						−27	
		287.1	x 61 km/ft								
			50.02 km								

δ = 0.29 km   ΣΔs = −2.5 m   Mean ΔH = −123.395 ÷ 200 = −0.61698 m

REMARKS:
Vertical mark rdg .81
Rod 1 constant +592.50
593.31
Staff inaccessible. Leveled to 9.00 ft graduation.
.80
+592.50
593.30

Figure 12-1. Micrometer observations

Turning plates should only be used on pavement or hard packed soil and only when absolutely necessary.

d. General connections between RDBM and DBM for existing PICES projects.

(1) Use SR/DR leveling via shortest route between RDBMs and DBMs.

(2) Double run only if external misclosures exceed tolerances.

(3) Ensure direct route from RDBM to structure monitoring points.

e. Spur leveling techniques or open-ended lines.

(1) Use single rod only (Rod A).

(2) Up to three instrument setups are allowable. (If more than three, double run back to starting BM and verify internal misclosure.)

(3) Start spur from a rigid BM and not from a TBM.

(4) Keep backsight/foresight distances within 1 m -- individual and accumulated.

(5) Multiple foresight shots are allowable from a single backsight assuming distances are allowable. Record similar to conventional leveling.

(6) Verify external misclosure on site -- re-observe, as required, using DR/DR methods.

(7) Single rod leveling methods may be employed for main connection lines between DBMs and BMs, should such methods prove to be more efficient.

(8) Observing and recording methods are similar to conventional leveling procedures, as modified for micrometer leveling.

f. Internal misclosure tolerances. Newly established points or for re-observations when external misclosures reject on single runs.

MISCLOSURE TOLERANCE = M = +3 mm $\sqrt{K}$

where K is measured in kilometers

If K < 1,000 m, then M = +3 mm × $\sqrt{K}$

MINIMUM M: 1 mm @ K less than 0.33 km

Rerun if in excess.

g. Instrument calibration requirements.

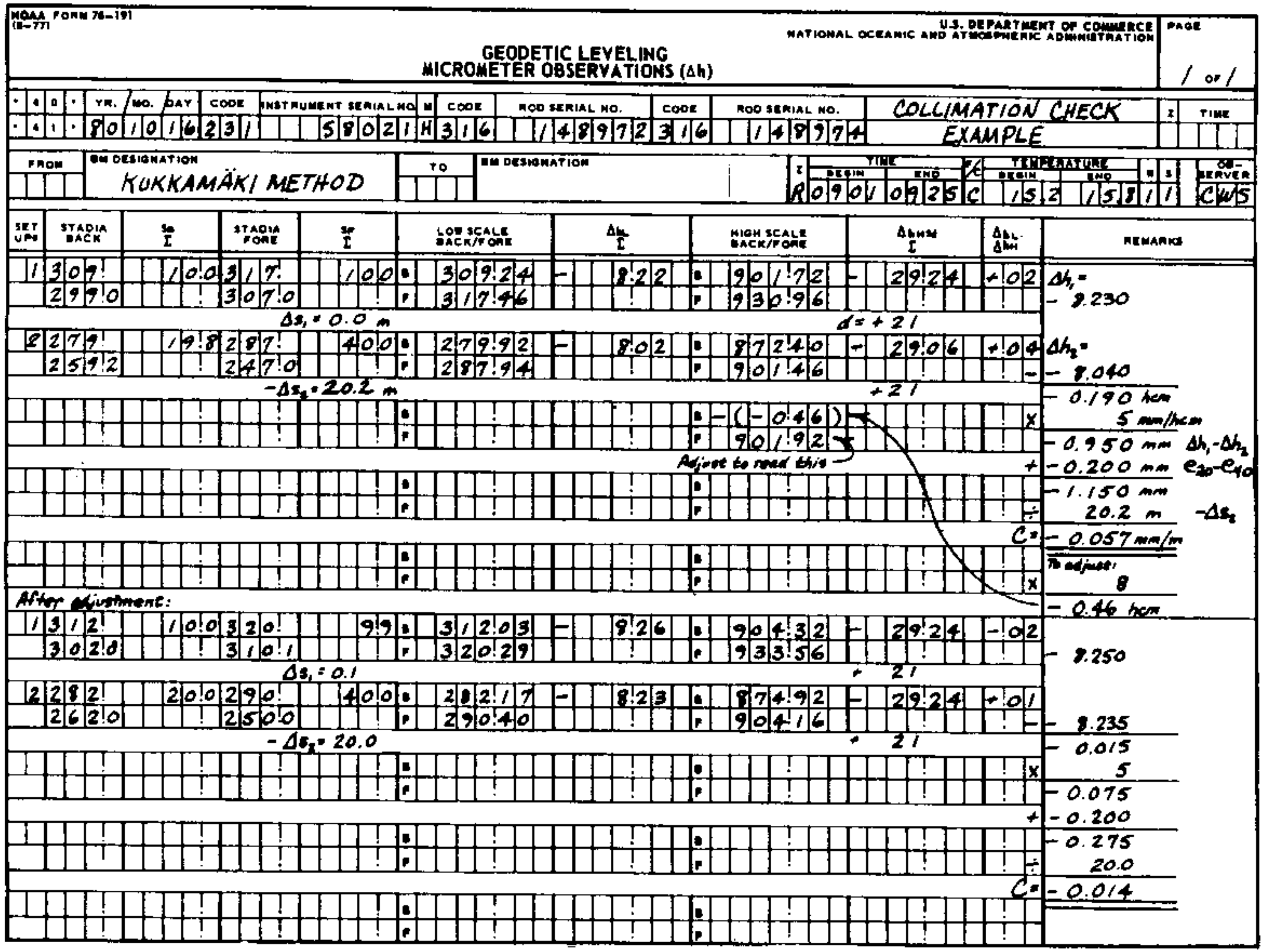
(1) Precise level rods and the instrument will be lab calibrated/maintained at least annually.

(2) C-factor collimation calibration. The C-factor shall be determined at the beginning of each PICES structure observation in accordance with the procedures outlined in Section 3 of NOAA Manual NOS NGS 3. The C-factor determination is done according to Kukkamaki's method and is also referred to as the Peg Test. The C-factor shall conform to the reject/readjustment criteria of Table 3-1 of NOAA Manual NOS NGS 3 which is 0.005 cm/m. Daily C-factor calibrations are not essential provided the instrument is consistently falling within 0.004 cm/m and backsight/foresight distances (individual setup and accumulated) stay within 1 m/2 m, respectively. In any event, C-factor calibrations shall be performed at least twice weekly when performing continuous leveling at a single PICES structure; upon commencing leveling at a new structure; or daily if the C-factors exceed prescribed limits. (See Figure 12-2.)

12-8. Leveling Computations and Reductions

a. Micrometer leveling data sheets will be checked in the field by an independent person (initial sheet accordingly), with the resultant differential elevation (DE) for each run clearly noted, along with pertinent plug offset characteristics, if any, and accumulated stadia lengths per circuit/section. Misclosure tolerances will thus, by this manner, be field verified/confirmed; accordingly, there shall be no further office verification of the basic observational data sheets -- the validity of internal/external closures having been made in the field.

b. Field sketches of level circuits/section/loops/spurs shall clearly show observed elevation differences, leveling direction, and stadia distances, all taken directly from the (checked) micrometer leveling recording forms. From such a sketch, elevations may be easily carried forward from the RDBM -- an essential computation in verifying external misclosures and should be stapled to all the data sheets acquired for an individual PICES structure. Elevations carried forward (from the RDBM) may be listed on a separate sheet, (i.e., an abstract).



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GEODETIC LEVELING
MICROMETER OBSERVATIONS (Δh)

• 4 0 •	YR.	MO.	DAY	CODE	INSTRUMENT SERIAL NO.	M	CODE	ROD SERIAL NO.	CODE	ROD SERIAL NO.		Z	TIME
• 4 1 •	90	10	16	231	5802	1 H	316	148972	316	148974	COLLIMATION CHECK EXAMPLE		

FROM	BM DESIGNATION	TO	BM DESIGNATION	Z	TIME BEGIN	TIME END	F/C	TEMPERATURE BEGIN	TEMPERATURE END		OBSERVER
	KUKKAMÄKI METHOD			R	0901	0925	C	15.2	15.8	1 1	CWS

SET UPS	STADIA BACK	Sb Σ	STADIA FORE	Sf Σ	LOW SCALE BACK/FORE	Δh Σ	HIGH SCALE BACK/FORE	ΔhHM Σ	ΔhL-ΔhH	REMARKS
1	309	10.0	317	100	B 309.24	− 8.22	B 901.72	− 29.24	+02	Δh₁ =
	2990		3070		F 317.46		F 930.96			− 8.230
	Δs₁ = 0.0 m						d = +21			
2	279	19.8	287	400	B 279.92	− 8.02	B 872.40	− 29.06	+04	Δh₂ =
	2592		2470		F 287.94		F 901.46		−	− 8.040
	−Δs₂ = 20.2 m						+21			− 0.190 hcm
					B		B −(−0.46)		×	5 mm/hcm
					F		F 901.92			− 0.950 mm Δh₁−Δh₂
							Adjust to read this		+	− 0.200 mm e₂₀−e₄₀
					B		B			− 1.150 mm
					F		F		÷	20.2 m −Δs₂
									C =	− 0.057 mm/m
					B		B			To adjust:
					F		F		×	8
After adjustment:										− 0.46 hcm
1	312	10.0	320	9.9	B 312.03	− 9.26	B 904.32	− 29.24	−02	
	3028		3101		F 320.29		F 933.56			− 9.250
	Δs₁ = 0.1						+21			
2	282	20.0	290	400	B 282.17	− 8.23	B 874.92	− 29.24	+01	
	2620		2500		F 290.40		F 904.16		−	− 8.235
	−Δs₂ = 20.0						+21			− 0.015
					B		B		×	5
					F		F			− 0.075
									+	− 0.200
					B		B			− 0.275
					F		F		÷	20.0
									C =	− 0.014
					B		B			
					F		F			

Figure 12-2. C-factor collimation calibration, Kukkamaki example

12-9. Office Computations, Reductions, and Adjustments

Presuming the above field computations, checks, and sketches are adequately performed, no formal office reverification of field data need be performed. Only a verification of the abstracted elevations should be required -- and compiling these values into the current PICES report. Examples of settlement tabulations and graphical plots showing historical trends are found in EM 1110-2-4300.

a. In general, no rigorous least squares (condition) type adjustments are necessary for PICES projects of limited magnitude wherein no sophisticated weighting method is effective. Redundant elevations (i.e., computed from different loops on circuits from the RDBM) may be simply averaged (meaned) regardless of lengths run. Since most PICES structures will involve single run lines run directly from the RDBM, final adjusted structure elevations are simply algebraic accumulations of DEs from the RDBM -- using field verified sketch/abstract data.

b. More sophisticated leveling adjustment procedures may be necessary in the case of:

- Newly established projects.

- Settlement anomalies (DBM or structure points).

- Abnormal movement of RDBMs or DBMs.

- Redefinition of RDBM using past data.

c. Tabulate carried forward elevations or averaged elevations, from the field sketch/abstract, holding the historical RDBM fixed and computing changes in elevation from prior PICES observations. Anomalies should be noted on the PICES report tabulation. Recommendations to change the RDBM (to another DBM) should be noted and pursued accordingly.

d. Reported elections of screw-in (or male insert) structural reference points (i.e., females) should clearly identify the type of male insert employed on the PICES report for the structure. Such identification (by male part/ serial number) is critical if male insert elevations are eccentric to the female plug. Monitoring of such types of points should be avoided in the future -- in lieu of standard bronze discs where no vertical eccentricity problems exist. (Loss of a male insert nullifies all future PICES settlement comparisons.) Pending eventual conversion to standard discs, recordation of male inserts is critical.

e. Record elevations to the nearest ten-thousandth (0.0001) m on final reported elevations and settlement changes. Presumptions of higher short-term or long-term accuracies are unwarranted, given procedural methods, misclosure tolerances, and potential settlement of DBMs and structures. Elevations (and elevation differences) on field sketches and abstracts should be tabulated to the nearest 0.0001 m.

12-10. PICES Micrometer Alignment Deflection Measurements-General

This section describes the techniques and specifications for measuring relative deflections using theodolites and precision micrometer caliper targets. Micrometer deflection measurements will yield accuracies that are far superior to geodetic techniques described in previous chapters; however, these deflection measurements are relative and not necessarily absolute movements. Accordingly, micrometer measurements are intended to monitor relatively short-term deflections in a structure monolith, wall, tower, etc., due to varying hydraulic head, temperature, curing, or other physical effect. Forced-centering of both the instrument and micrometer target is critical if accurate repeatability is desired. Supplemental information on micrometer deformation observations is found in EM 1110-2-4300.

12-11. Micrometer Deflection Observations

Short-term horizontal deflections or deformations of points on structural sections can be easily monitored by observing alignment variations with a precision theodolite relative to (presumed) fixed points on a baseline not influenced by the structure. In essence, the deflection of a point relative to a fixed baseline is observed either by micrometer target methods or by observing the actual deflection angle directly (and computing the relative lateral movement indirectly). The theodolite and reference target(s) must be set up on concrete instrument stands using rigid forced-centering devices. Structure monitoring target points (or plugs) are normally set (grouted) within ±0.5 inch from the reference baseline from which deflections are referred.

12-12. References

Added background on relative deflection measurement techniques are described in EM 1110-2-4300.

12-13. Expected Deflection Observation Accuracies

Given the centering limitations of a precision theodolite, cross hair delineations, theodolite vertical alignment limitations, and numerous other factors, absolute horizontal deflections can be measured to approximately ±0.01 inch over typical distances involved. This value is relative to the fixed alignment baseline on which the theodolite and reference target are set. In some instances (e.g., along lock walls) this fixed baseline may not be perfectly stable, and this may further degrade the ultimate accuracy of measuring deflections in individual structural sections. In addition, other short-term effects may mask the relative accuracy of deflection observations. These include short-term temperature changes (sun-cloud), power plant machinery, lock operation, etc. Observers should exercise judgment regarding the ultimate accuracy of micrometer measurements when local conditions are impacting observations.

12-14. PICES Micrometer Alignment Requirements and Instructions

PICES alignment requirements for each structure will be listed in tabular form on project instructions -- identifying the baseline reference points (instrument/target stands), the deflection points to be observed, and structure loading requirements (e.g., lock fill elevations). Requirements for establishing new alignment points and constructing reference baseline instrument/target stands will be detailed as required.

12-15. Instrumentation Requirements

a. Wild T-2 or T-3 theodolite with forced-centering tribrach. Other similar instruments (e.g., total stations) may be used.

b. Targets: Inverted “V” or conic plug inserts.

c. Alignment micrometer with forced-centering plug insert. Inverted “V” or conic targets mounted on micrometer. See EM 1110-2-4300 for details on forced-centering monument construction and monolith alignment marker design.

d. Recording format. Use a standard field survey book for both observations, computations, and adjustments of data.

12-16. Observing Procedures

a. Theodolite and target are force-center mounted on each end of the reference baseline. Baselines typically range from 100 to 1,000 feet in length, depending on the structure. The baseline is established perpendicular to the direction in which deflection observations are required.

b. After force-centering the theodolite, accurately level theodolite to its reversing point -- relevel to the reversing point before each observation. This theodolite leveling/releveling procedure is critical. In addition, parallax is removed from the theodolite’s cross hairs. The reference target on the opposite end of the reference line is aligned by forced-centering, and ensuring the target is aligned vertically over the plug center.

c. The theodolite’s vertical hair is centered on the reference target and five (5) alignment deflections are observed with the theodolite in Direct position only. For each observation, initial on the reference target, drop vertical line of sight, and move the alignment micrometer/target to collimation with T-2. Radios may be required for communication between the instrument man and micrometer operator. Ensure micrometer device is as level as possible. Also record pertinent structural load and temperature conditions.

d. Observe five deflections with the alignment micrometer in the LEFT position (i.e., micrometer is to left of baseline as viewed from the theodolite’s position).

e. Rotate alignment micrometer 180 degrees to its RIGHT position, and observe five deflections (theodolite is still in Direct position). Relevel theodolite (to its reversing point) before sighting on the reference target. (Leveling of the micrometer is critical on the lateral axis.)

f. Always run the micrometer against the spring. After each deflection observation, the micrometer should be backed off a few hundredths of an inch.

g. Read alignment micrometer to nearest ±0.001 (thousandth) inch.

h. Determine the mean of both LEFT and RIGHT micrometer observations (five each) to nearest 0.001 inch. The difference between the mean of the LEFT set and the mean of the RIGHT should not exceed ±0.02 (two-hundredths) inch. If the difference between the two means does exceed this limit then both the LEFT and RIGHT set must be reobserved. Large variations probably indicate poor target centering, parallax not eliminated, or mislevelment of the theodolite.

i. Check internal rejection criteria. Reject if measurement is $\pm$0.02 inch from the mean.

j. Check external rejection criteria. Check previous PICES report for potential blunders.

k. There are no micrometer calibration requirements during observations since reversing the micrometer to the LEFT and RIGHT positions eliminates index error in the device.

l. There is no need to reverse the theodolite, given the small vertical deflections involved, and higher errors inherent from other sources. If significant vertical deflections are involved, then non-verticality of the theodolite could inject errors. Also, the vertical cross hair should be periodically checked and adjusted, in accordance with the manufacturer's manual. The theodolite itself should be serviced and calibrated annually.

12-17. Field Computations and Reductions

a. The final left/right deflection angle will be computed in the field after each alignment observation, and noted in the field survey book. Accordingly, no office recomputations will be required. All field reductions shall be independently checked in the field.

b. From the meaned micrometer LEFT/RIGHT readings, compute the adjusted deflection as follows:

Deflection = D = (ML - MR)/Z

where

D = "+" RIGHT deflection off baseline to structure point as viewed from theodolite position

ML = mean of five LEFT micrometer readings on baseline

MR = mean of five RIGHT micrometer readings on baseline

c. Round adjusted deflection to the nearest 0.01 inch.

d. The sum of the micrometer LEFT and RIGHT means will not necessarily total to 1.000 inch, given the micrometer index errors.

e. Office tabulations. Simply tabulate field-computed deflection values onto the PICES report. Note all local conditions (i.e., water level, temperature, etc.) for each observed deflection. See sample recording formats in EM 1110-2-4300.

12-18. PICES Crack and Joint Measurement Procedure - General

This section describes absolute micrometer joint or crack measurement procedures using micrometers. Relative displacement techniques are not covered -- see EM 1110-2-4300. PICES crack/joint observations are measured relative to grouted bronze plugs set 12 inches (±) on center across a concrete crack or structural construction joint where periodic monitoring is required. Monitoring points are usually set on each adjacent monolith. Monitoring is performed periodically for long-term trends or during short-term load deformation studies. Often, three plugs are set across each crack or joint in a triangular pattern. In most cases, two opposite plugs set perpendicular to the joint/crack plane will be adequate. Expected short-term accuracy is on the order of ±0.0005 inch, relative to the fixed calibration reference bar. Errors due to the nonalignment (vertical) of the crack plugs relative to one another could affect observational accuracy (and long-term repeatability) upwards of ±0.01 inch. Given all of the above errors and uncertainties, estimated long-term crack measurement accuracy is at the ±0.005- to 0.010-inch level, totally independent of short-term movements in the structure due to load or temperature influences.

12-19. PICES Requirements and Instructions

Crack and joint measurement requirements are typically listed in tabular form, including instructions for varying hydraulic head levels against the monoliths, if applicable. Requirements and instructions for setting new monitoring points will be provided as required. Structure loading requirements will also be provided for each new observation point specified.

12-20. Instrument and Equipment

a. Inside micrometer. Any standard machine tooling inside micrometer may be used for crack measurements. Precision calipers may also be employed in lieu of an inside micrometer.

b. Inside micrometer calibration bar. A 12-inch center to center standard reference may be used for all micrometer observations. An independent recalibration of this bar is necessary to monitor long-term stability.

c. Plug inserts. Stainless steel threaded half-inch inserts are used and inserted into the dual or triad points across monolith joints or cracks. Inserts are stamped to ensure consistent use on periodic measurements. The 0.500-inch O/D inserts should be precision machined to an accuracy of ±0.001 inch and verified by micrometer measurement.

12-21. Crack Measurement Techniques

a. Insert plug pins and measure crack or joint distance using an inside micrometer or caliper.

b. Read micrometer/caliper values to nearest 0.001 inch.

c. Read in both directions (i.e., reverse micrometer ends) between crack plugs and mean result to nearest 0.001 inch.

d. Hold micrometer ends as low as possible on each plug pin. Gently rotate each end for minimum distance observation.

e. Readings in each direction should not vary by more than ±0.001 inch unless it can be verified that the crack plugs are grossly misaligned vertically. This can be verified by raising the micrometer at both ends to confirm nonverticality of the grouted plugs. Do not attempt to interpolate between 0.001-inch values. Record a single minimum reading for each direction and mean as required.

f. The following applies to an inside micrometer with dial: Lock micrometer to nearest 0.025-inch division and use dial indicator to obtain minimum distance. (Maximum reading on scale which is subtracted from the preset micrometer value):

Example:

Micrometer set at:	11.475 inches
Maximum dial scale reading (minimum distance):	-0.021 inch
Observed uncorrected micrometer length:	11.454 inches

g. Ensure dial range is within 0.025-inch micrometer setting range to avoid misreadings and ensure relatively constant spring tension.

12-22. Micrometer Calibration Bars

a. The calibration bar is used to ensure the micrometer is accurate by verifying a 12.000-inch center to center distance. The calibration bar should be kept shaded. Calibrate caliper and/or micrometer prior to PICES structure observation, using an independent reference. Single meaned forward/backward micrometer positions on the calibration bar should be observed/recorded to the nearest 0.001 inch.

b. Example of calibration for Starrett Micrometer (similar operation required for Helios Caliper).

	FORWARD	BACKWARD
Micrometer	11.475	11.475
Dial	-0.021	-0.020
Reading	11.454	11.455

Meaned calibration reading = 11.454 inches

CALIBRATION CORRECTION	
(Nominal calibration bar length)	12.000
- (Calibration reading)	-11.454
Calibration correction	00.546 inch

c. The above micrometer and caliper calibration correction is applied to all subsequent crack readings.

d. Typical crack observation (Starrett Inside Micrometer). Typical field book entry:

Cross Florida Barge Canal
Inglis Lock & Spillway

Points:		IL19N4 to IL19N5
19 July 1984		0845 am
Mic	-	Bergen
Notes	-	Noles, Bergen
T	-	86° F, Rain

Lock full @ 36.0’ elev.

FWD		BACK	
11.475	Mic	11.475	
-0.019	Dial	-0.020	
11.456		11.455	Mean = 11.456 inch

Calibration correction = +0.546 inch

Corrected plug reading (IL19N4 to IL19N5) = 12.002 inches

The corrected plug-to-plug reading (12.002) may be directly inserted on PICES tabulation report; no further adjustments are required.

e. Typical plug pin convention for Triad Crack/Plug Configurations. Three marked pins shall be used in the same plug upon each PICES revisit, per the following convention:

“L” Lowest numbered crack plug
“H” Highest numbered crack plug
“b” “Blank,” in medium numbered crack plug

i.e. Inglis Lock

PLUG	PLUG
IL19N4	“L”
IL19N5	Blank
IL19N6	“H”

f. Normally, only one forward/reverse observation will be required for each pair of plugs, approximately a 1- to 2-minute procedure. Additional observations under different structural loading conditions or temperature conditions will not be performed unless specifically requested in the project instructions. In cases where observations are taken over varying points in time or condition, they will not be meaned, given the external structural variability of the measurements. (All PICES observations are only valid for the finite period in which they are taken given the external influences, primarily by the structure and to a lesser extent the instrumentation employed. This applies to vertical, horizontal, and alignment observations also).

g. Internal rejection criteria are ±0.001 inch between each direction reversal and ±0.001 inch from nominal calibration bar constant. Failure to obtain agreement in each direction may be due to nonverticality of the plugs, in which case no re-observations are necessary.

h. There are no external rejection criteria other than a blunder check using prior PICES observations (reports).

i. Standard field survey books for both observations and corrected/adjusted lengths are normally used for record keeping.

12-23. Periodic Calibration Requirements on Micrometer

a. Independent annual calibrations should be performed on the following components:

- Inside micrometer or calipers.
- Reference calibration bar.
- Threaded 1/2-inch plug inserts.

b. Calibrations should be checked over the normal temperature range which these devices are subject to in order to determine if expansion (temperature dependent) corrections become significant.

c. There is no method for eliminating the error due to nonverticality of the plugs other than using identical inserts on each visit. Use of inside/outside precision calipers will eliminate most independent calibration requirements other than the calipers themselves and ensure true roundness and alignment of the threaded plug inserts. The need for a reference calibration bar may also be eliminated.

12-24. Data Computations and Reductions

a. All PICES observations and reductions shall be performed and verified in the field, directly into the field survey book. Micrometer data are corrected for calibration constants as shown above. Quick comparisons should be made with previous PICES observations to preclude against blunders.

b. Office processes are not required other than tabulating field reduced distance onto PICES reports and computing changes from past readings. Standard forms for periodic crack measurements are also found in EM 1110-2-4300.

12-25. PICES: Horizontal EDM Observations-General

The following procedures apply to structural deformation observations utilizing EDMs. EDMs include either standalone or electronic total stations. Distances to structural monitoring points are observed from one or more rigid instrument stands or tripods over “fixed” points. The positioning of the fixed points is not influenced by movement of the structure and is presumed to be static. The fixed points constitute a local baseline for each structure. Structural movement is then determined relative to these external points. The external reference points are set such that the relative movement vector being measured is generally perpendicular to the structure's probable plane of failure. The field method for obtaining the EDM measurements for PICES is referred to as the RLR/Robertson Method, as detailed in prior chapters. The RLR method will provide sufficient relative accuracy measurements for most USACE structural monitoring applications. This section describes the general procedures used in measuring actual distances with typical EDM equipment. Establishment of the reference network and periodic measurement procedures are covered. The RLR method requires no EDM calibration or meteorological conditions correction. Rather, the distance between two fixed points (baseline distance) at the structure is measured and compared to the published distance (distance recorded in the PICES tabulation). If there is a difference upon comparison of the two distances, then either change the ppm reading on the instrument to match the published distance or compute the ratio of the measured distance to the published distance. The distances to the structure points are then measured. If measurements are made for more than 30 minutes, the baseline distance must be checked and the above procedure repeated if there is a difference between the measured and published distances. Continue measuring distances to structure points. Distances measured using the option where the ppm is adjusted to match the published distances can be entered directly into the tabulation, and the change and cumulative change computed and also entered into the tabulation.

12-26. Required Accuracy

The estimated accuracy of any individual EDM length observation measured over typical distances is ±0.002 to 0.005 m. This estimate is based on potential error sources involving:

- EDM rated precision point centering limitations -- instrument and reflector.
- Atmospheric corrections and reductions, or variations during RLR method.
- Short-term structural deformations occurring during actual PICES measurement process.
- Numerous other factors well documented in geodetic reference texts and manuals.

Since most PICES projects involve relatively short EDM lengths (i.e., between 100 and 1,000 m), errors due to poorly observed atmospheric corrections and slope/horizontal reductions are relatively insignificant (less than 1-3 mm) compared to EDM instrument limitations and instrument/reflector centering uncertainties, among others. In some instances, over rigid forced-centering bases, accuracies may be obtained down to the 0.003 m level.

12-27. PICES Requirements and Instructions

Requirements for recurring PICES EDM observations will be received in either tabular or plan form, detailing the lengths to be observed to each particular structural monitoring point. A single length implies a unit vector comparison. Requirements for establishing new monitoring points and constructing reference instrument stands will be detailed as necessary.

a. The EDM instrument must be paired with specific (numbered) reflector.

b. Both the instrument and reflector should be mounted using forced-centering devices. Wild tribrachs with standard target level vials may be used to level tribrach housing over plugs. Threaded aluminum rods for direct insert in monitoring plugs may be used to support reflectors.

c. Engineer scales may be used for measuring instrument/reflector heights over base, as needed for slope/horizontal distance reduction.

d. Standard Wild-type tripods with Wild tribrachs should be used for nonforced-centering mounts. Use of tripods is not recommended for PICES work due to difficulty in accurately plumbing instrument/reflector over marks.

e. Standard field survey books may be used for recording all observations, computations, and reductions.

12-28. General EDM Observing Procedures for Lines Less Than 1,000 M in Length

a. Only Wild interchangeable tribrachs shall be used such that the instrument/reflector may be readily interchanged without affecting centering of the tripod/tribrach mount. Any other type of equipment shall be considered unacceptable.

b. Only one instrument/reflector combination shall be used for a particular line. The serial numbers of the instrument and reflector shall be recorded for each observation to ensure and verify this fact.

c. Accurately centering instruments, reflectors, or tribrachs over the marks is one of the most critical processes involved in short-range EDM observations. In order to ensure that centering errors are minimized, the following procedures should be followed for all structural deformation EDM work.

(1) Wild tribrachs shall be accurately plumbed using the built-in optical plummet. Optical plummets shall be calibrated at the beginning of each project using the procedures outlined in the manufacturer's manual. Failure to perform/certify/record this calibration process can be grounds for rejecting all subsequent EDM data obtained with an uncalibrated tribrach.

(2) Tripod heads shall be aligned as nearly horizontal as is possible, prior to final centering procedures.

(3) Final tribrach leveling and centering shall be performed using a level vial from either a mounted theodolite or a standard Wild target. The built-in bull's-eye level is not considered accurate enough for this process and should only be used for rough tripod head alignment. All centering leveling vials should be calibrated at the beginning of each project and this fact so recorded during that process.

(4) In general, all tripod/tribrach centering shall be performed to an accuracy of ±1 mm.

(5) When using a tripod in lieu of forced-centering, and weather conditions permit, optical centering may be checked using a standard plumb bob. Significant disagreement (say more than 1 mm) would be grounds for immediately recalibrating all optical plummets and level vials.

d. Once tripods and tribrachs have been accurately centered over each end of the line, then the EDM instrument and reflector may be inserted into the tribrachs without further adjustment. Extreme care shall be taken to avoid disturbing the tribrach centering during the insertion and measurement process. Since each line may be measured in both directions, the instrument/reflector swapping process shall be carefully executed to avoid disturbance of the centering alignment.

e. Upon completion of all observations from a particular tripod, a final level and centering check shall be performed to ensure no movement has occurred during this process. If no movement is detected during this final check, then the entire observation process shall be repeated.

f. In precise surveys, towers, stands, and tripods must be substantial. The use of driven stakes or some type of quick setting cement or dental plaster for tripod leg support may be required. Catwalks, support away from tripod legs, may be necessary under some soil or platform conditions to ensure that the instrument/reflector is unaffected by motion around it.

g. When relatively short reflector rods are screwed directly into grouted plugs, it is critical that the same rod is used for each successive PICES project. Therefore, the rod number should be recorded such that this rod is always used at a particular plug. Reflector HI's should be kept as low as possible to minimize potential nonverticality of the rods.

12-29. EDM Observing Repetitions

a. Five (5) repeated observations should normally be taken, or approximately 30 seconds of observations. A second series of 5 observations shall be taken after repointing on the target. Consult manufacturer's recommendations for additional guidance.

b. Record repeated observations to the least count on the EDM -- the nearest 0.001 or 0.0001 m. Mean the result to the same degree of precision.

c. Distances need only be observed in one direction when the instrument is set up on positive centered concrete instrument stands. Measure both directions when using tripod supports. On some projects, double measuring need only be performed if a one-way distance deviated over 5 mm from previous PICES observations.

d. Distances between fixed instrument stands, if required, shall be observed in both directions.

e. The following observations shall be made for each EDM distance measured.

- Heights of instrument and reflector (HI/HR) shall be accurately measured and recorded at each end -- to nearest 0.01 foot.

- Instrument stands with elevations determined relative to domed plugs must be corrected accordingly when HI measurements are relative to the plug base.

- The EDM instrument shall have the electro-optical center calibrated and marked such that accurate instrument heights may be determined for each observation. Likewise, the optical center of the reflector shall be equally calibrated and marked.

f. The previously determined system constant for an EDM shall be recorded in the field book for each observation. Accordingly, the instrument and reflector serial numbers must be noted in the field book to ensure the calibrated pair is correct. Incorrect instrument/reflector serial numbers and system constant will result in rejection of all data.

g. The rigid reflector rod number, when used, must be recorded in the field book.

h. Figure 12-3 depicts a typical field EDM observation and reduction.

12-30. Internal EDM Rejection Criteria

a. The spread from the mean of the observations (2 sets of 5) shall not vary by more than 0.002 m. If 0.002 m is exceeded, re-observe the series.

b. Measurements taken in both directions should agree to 0.002 m after measurements are corrected for slope and atmospheric conditions, as required.

12-31. EDM Computations, Reductions and Adjustments

a. In performing the procedures outlined above, final corrected horizontal distances will be computed and verified/checked in the field. The following corrections/reductions will be performed/corrected in the field:

- System constant.
- Horizontal eccentricities (if any).
- Slope to horizontal correction.

b. No corrections to sea level need be applied in PICES projects involving short lines (i.e., less than 1,000 m) or projects near sea level (e.g. in Florida). Final reduced slope distances (corrected for atmospheric observations) shall be reduced to horizontal distances using the elevation differences determined from differential levels. Zenith distances (vertical angles) are rarely used for determining EDM elevations. Accurate heights of instruments are critical; accordingly, these values shall be precisely measured for each observation (using a rod scale or other equally accurate method). Field notes and computation/reduction recording forms shall show the application and/or consideration of all the correction factors described above. Reduced horizontal lengths should be checked and initialed in the field.

c. In some cases where only relative vector movement is being monitored, slope-horizontal reductions need not be applied if distances are relatively long and HIs are of average amounts.

12-32. Office Computations and Adjustments

Since incoming field observations are fully corrected and reduced to horizontal, no further office adjustment of the individual length observation is necessary. PICES report tabulations are performed in the standard manner showing single lengths plus relative changes from past observations.

PROJECT	PAGE	COMPUTED BY	DATE
PICES: HORIZONTAL EDM OBS	__ OF __	Bergen	27 July 84
SUBJECT		**CHECKED BY**	**DATE**
TYPICAL FIELD BOOK DATA & COMPUTATIONS		Noles	27 July 84

THE FOLLOWING DATA MUST BE FIELD RECORDED/COMPUTED FOR EACH PICES EDM OBSERVATION. NO RIGID RECORDING FORMAT IS SPECIFIED. (THE SAMPLE OBSERVATION IS TOTALLY SIMULATED.)

	∧ CFBC 992	ϕ CFBC 993	
			27 July 1984
			INGLIS Loch
			(Full @ 36.3)
MARK	Instrument Stand	TRIPOD	CLEAR
Instrument	AGA # XXXX	REF S/N XXX	∧ – Noles
			◊ – Bergen
Elevation	99.2198✓ m	97.6147✓ m	ϕ – Bergen
Plug Insert Office	−0.051✓ m	n/a	Check – Noles
HI (ft)/m	(0'.73) + 0.226✓ m	(5'.62) + 1.713✓ m	T – 0847 AM
Elevation	∧ 99.3948✓ m	ϕ 99.3277✓ m	

	Set 1	Set 2	Temp (°F)	Press (in Hg)
	72.1084 m	72.1086 m		
	.1087	.1087	∧ 86/87	30.12/30.15
	.1081	.1088	ϕ 85/86	
	.1083	.1085	M 86 ✓	30.1 in Hg✓
	72.1085	72.1083		
Mean (set)	72.1084✓	72.1086✓	+16✓ ppm Dialed in AGA	

Mean of Sets	72.108 m✓	MET Corrected Slope Distance
	−0.002 m✓	System Constant (AGA # XXXX Ref/SN XXX) ~ 8 June 84 Calibration
	72.106 m✓	Corrected Slope Distance (T)

Δ elev = 0.0671✓ m

Corrected Horizontal Distance: $H = (T^2 - \Delta e^2)^{1/2}$ = 72.106✓ meters

HAD A REFLECTOR ROD BEEN USED THEN ITS SERIAL NUMBER WOULD HAVE BEEN RECORDED

Figure 12-3. Horizontal EDM observation